

Summary

Earthquakes have periodically occurred in and around Kentucky throughout history. An example is the June 8, 2003, Bardwell, Ky., earthquake (M4.0). The most widely felt and damaging earthquakes in the state are the great earthquakes that occurred in the winter of 1811-1812, which were centered in northeastern Arkansas, northwestern Tennessee, southwestern Kentucky, and southeastern Missouri: the New Madrid Seismic Zone. The 1811-1812 earthquakes caused damages (i.e., Modified Mercalli Intensity [MMI] of VII to IX) throughout much of the Commonwealth. The 1980 Sharpsburg earthquake caused significant damage (MMI VII) in Maysville. Although the causes of earthquakes are not fully understood and they are difficult to predict, they continue to occur in and around Kentucky. Earthquakes will affect humans, buildings, and bridges: this is called seismic hazard. The primary seismic hazard is ground motion generated directly by an earthquake. The level of ground motion depends on earthquake magnitude, distance from the earthquake center, and the type of fault. Generally, the larger an earthquake's magnitude, the stronger ground motion it will generate, and the closer a site is to the epicenter, the stronger the ground motion, and vice versa. In this study, we developed ground-motion hazard maps and time histories from all potential earthquake sources in and around Kentucky.

Two approaches are widely used in seismic hazard mapping: probabilistic seismic hazard analysis (PSHA) and deterministic seismic hazard analysis (DSHA). The two approaches use the same data sets, earthquake sources (where and how big), earthquake occurrence frequencies (how often), and ground-motion attenuation relationships (how strong), but are fundamentally different in final products. In PSHA, a series of probabilistic computations combine the uncertainties in earthquake source, occurrence frequency, and ground-motion attenuation relationship. PSHA predicts a relationship between a ground-motion value, such as PGA, and a chance that that value will be exceeded (hazard curve). PSHA addresses the chance of a level of ground motion being exceeded from all possible earthquakes. The ground motion derived from PSHA does not have a clear physical meaning, and is not associated with any individual earthquake. In DSHA, a particular seismic scenario is developed upon which a ground-motion hazard evaluation is based. The scenario consists of the postulated occurrence of an earthquake of a specified size at a specified location. The advantage of DSHA is that it provides seismic hazard estimates from earthquakes that have the most significant impact. This advantage is of significance in engineering practice.

The engineering seismic designs and standards used in the United States, as well as in the rest of the world, are based on what has been learned in coastal California. The ground motion specified for bridge design in California is the deterministic ground motion from the maximum credible earthquake (MCE). The ground motion from the maximum considered earthquake (MCE ground motion) was also recommended for building seismic design in California. In engineering practice in California, DSHA, not PSHA, is being used to develop the design ground motion. The purpose of this project is to develop ground motions, including peak values and time histories, for seismic analysis and design of highway bridges in Kentucky. Therefore, it is more appropriate to use DSHA for this purpose.

Ground-Motion Hazard Maps

Ground-motion hazards associated with three earthquake scenarios, expected earthquakes (EE), probable earthquakes (PE), and maximum considered earthquakes (MCE), were developed (Fig. 1). EE is defined in this study as the earthquakes that could be expected to occur anytime in the bridge lifetime of 75 years. EE is equivalent to the small earthquake defined in the existing AASHTO provisions and similar to the expected earthquake defined in the 2003 *Recommended LRFD Guidelines for the Seismic Design of Highway Bridges*. PE is defined as the earthquakes that could be expected to occur in the next 250 years. PE is equivalent to the moderate earthquake defined in the existing AASHTO provisions. MCE is defined as the maximum event considered likely in a reasonable amount of time. The phrase "reasonable amount of time" is defined by the historical or geological records. For instance, the reasonable amount of time for the maximum earthquake in the New Madrid Seismic Zone is about 500 years, based on paleoliquefaction records. The reasonable amount of time for the maximum earthquake in the Wabash Valley Seismic Zone is about 10,000 years. MCE is equivalence to the large earthquake defined in the existing AASHTO provisions and similar to the maximum considered earthquake defined in the 2003 *Recommended LRFD Guidelines for the Seismic Design of Highway Bridges*.

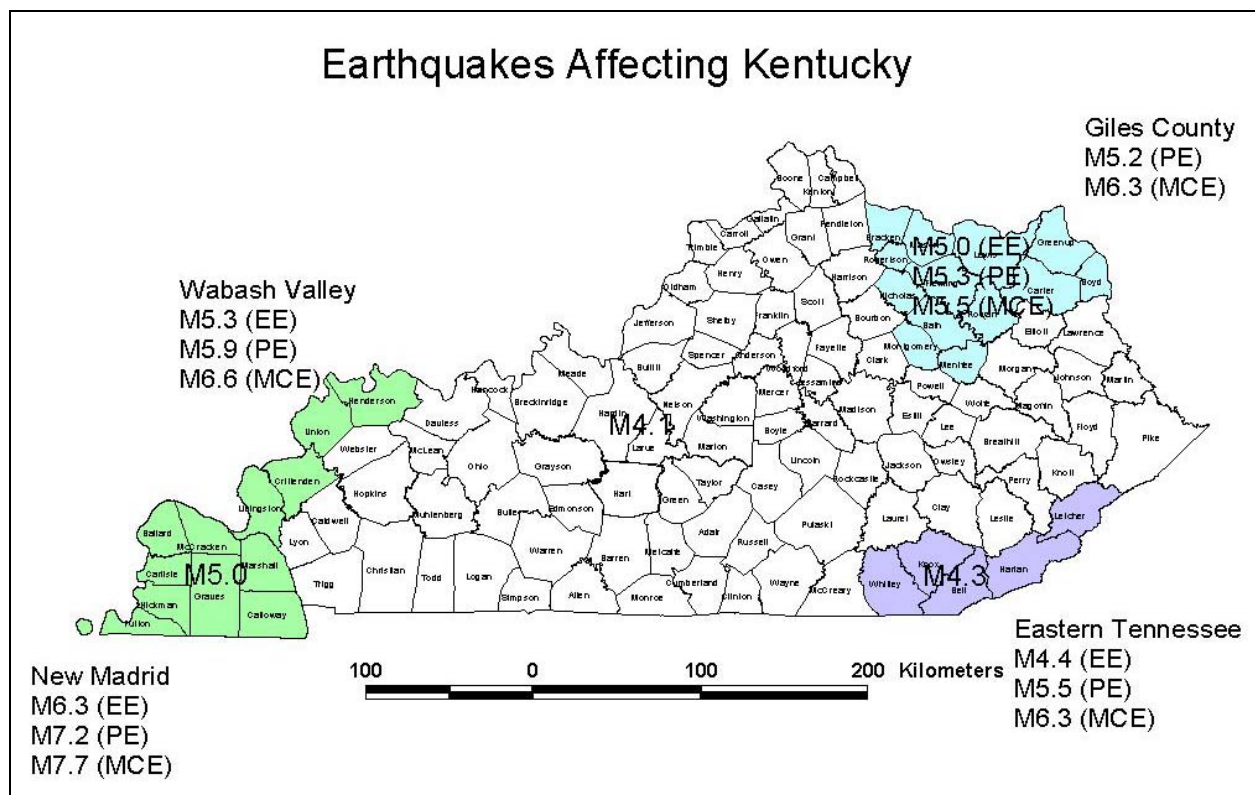


Figure 1. Earthquakes affecting Kentucky.

Three sets of hazard maps, depicting peak (horizontal) ground acceleration, and short-period (0.2 s) and long-period (1.0 s) response accelerations with 5 percent damping, for the three earthquake scenarios, EE, PE, and MCE, were developed (Figs. 2–10). The hazard maps predict the maximum median ground motions and response spectra at the county seats from all

earthquakes defined in each scenario. EE, PE, and MCE peak ground-motion hazard maps are equivalent to the maps of horizontal peak-particle acceleration at the top of rock with a 90 percent probability of not being exceeded in 50, 250, and 500 years, respectively, defined in KTC-96-4. The short- and long-period response accelerations, S_S and S_1 , for each earthquake scenario are equivalent to those defined in the 2003 *Recommended LRFD Guidelines for the Seismic Design of Highway Bridges*, and can be used similar to determination of design spectra in the general procedure. For example, S_S and S_1 for the expected earthquake in Paducah, McCracken County, will be 0.20g and 0.03g from Figures 3 and 4, respectively. S_S and S_1 for the maximum considered earthquake in Paducah will be 0.50g and 0.20g from Figures 9 and 10, respectively.

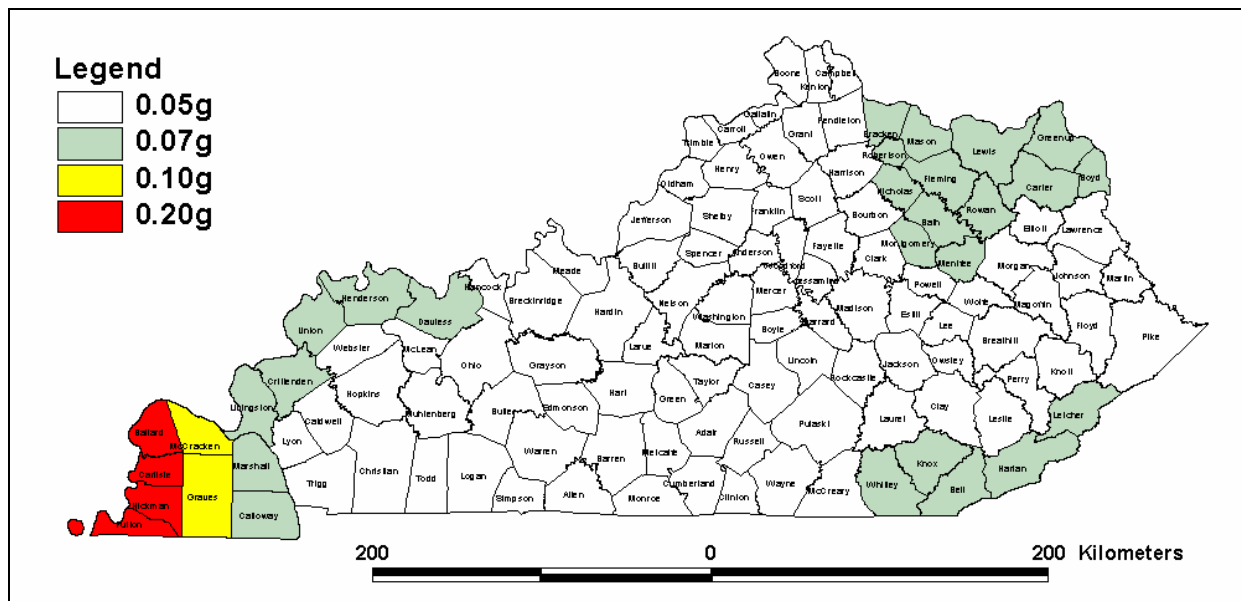


Figure 2. Expected earthquake peak ground acceleration (PGA) for Kentucky. The expected earthquake ground motion is equivalent to the ground motion with a 90 percent probability of not being exceeded in 50 years specified in KTC-96-4 (Street and others, 1996).

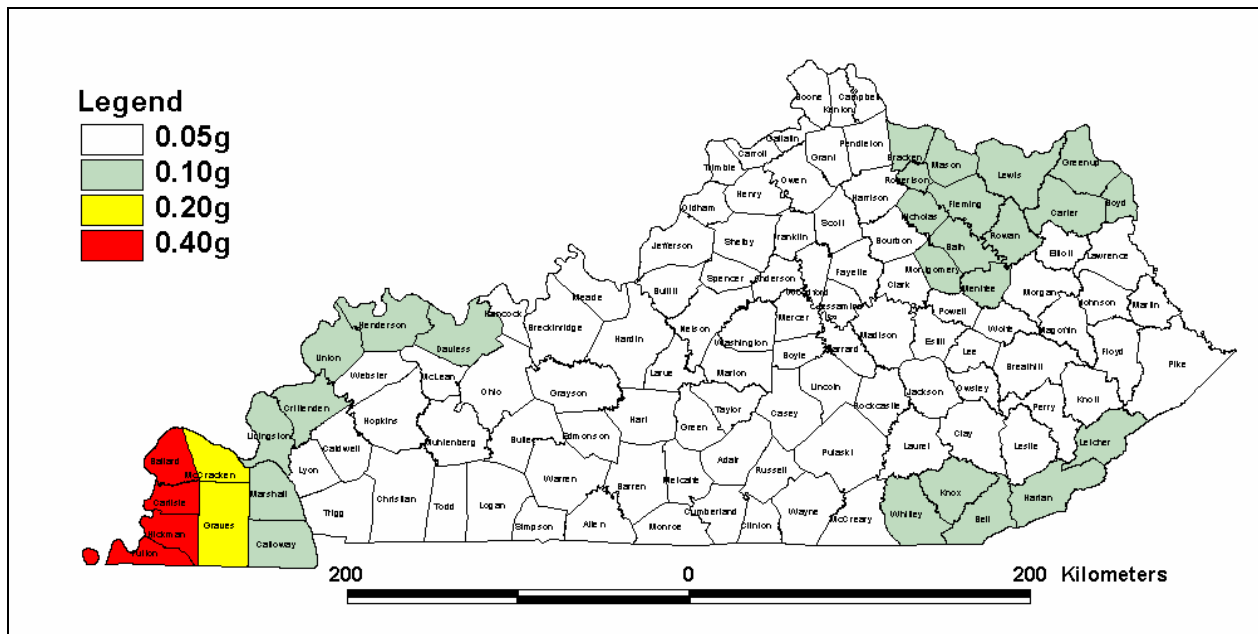


Figure 3. 0.2 second expected earthquake response acceleration (S_s) for Kentucky.

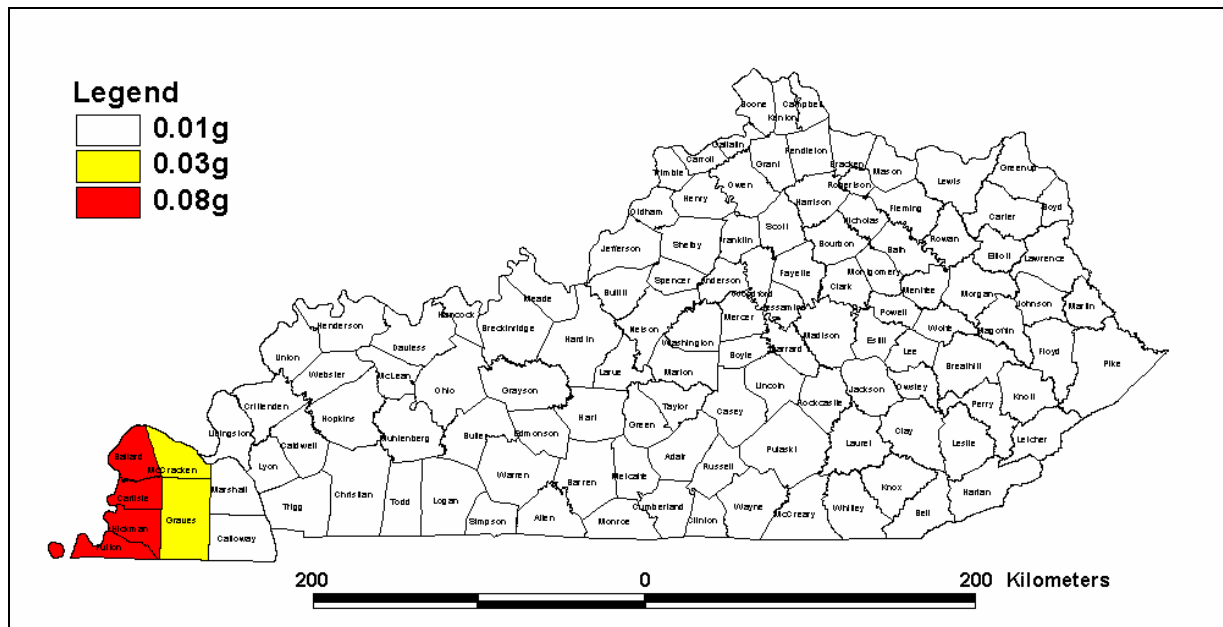


Figure 4. 1.0 second expected earthquake response acceleration (S_1) for Kentucky.

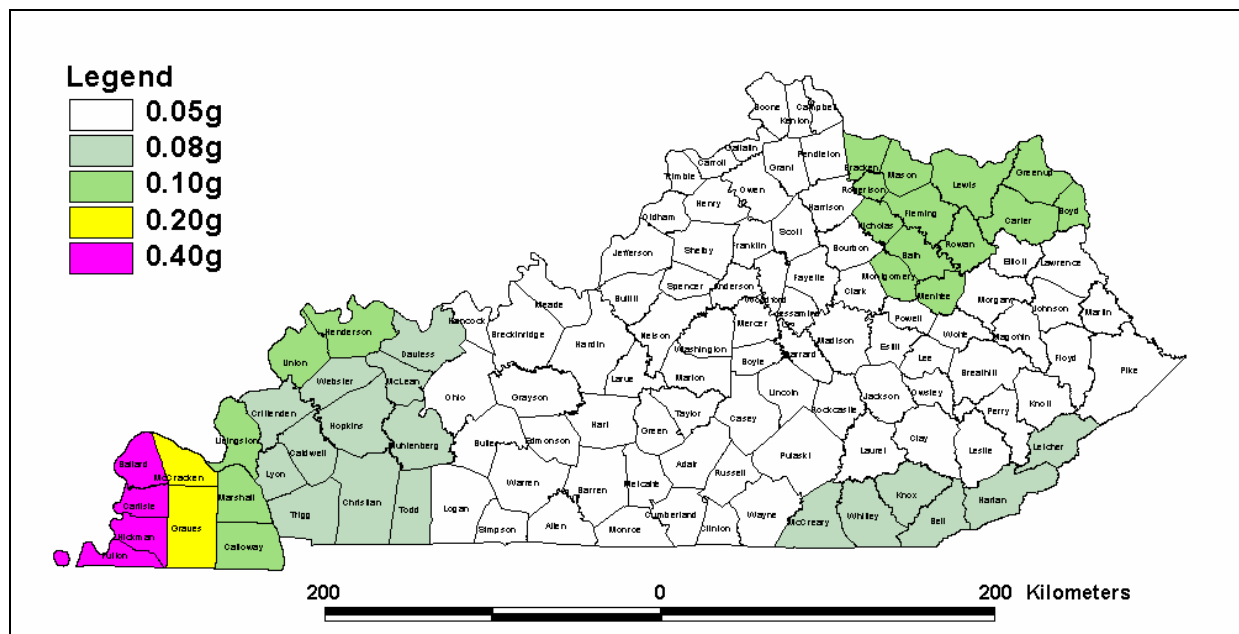


Figure 5. Probable earthquake peak ground acceleration (PGA) for Kentucky. The probable earthquake ground motion is equivalent to the ground motion with a 90 percent probability of not being exceeded in 250 years specified in KTC-96-4 (Street and others, 1996).

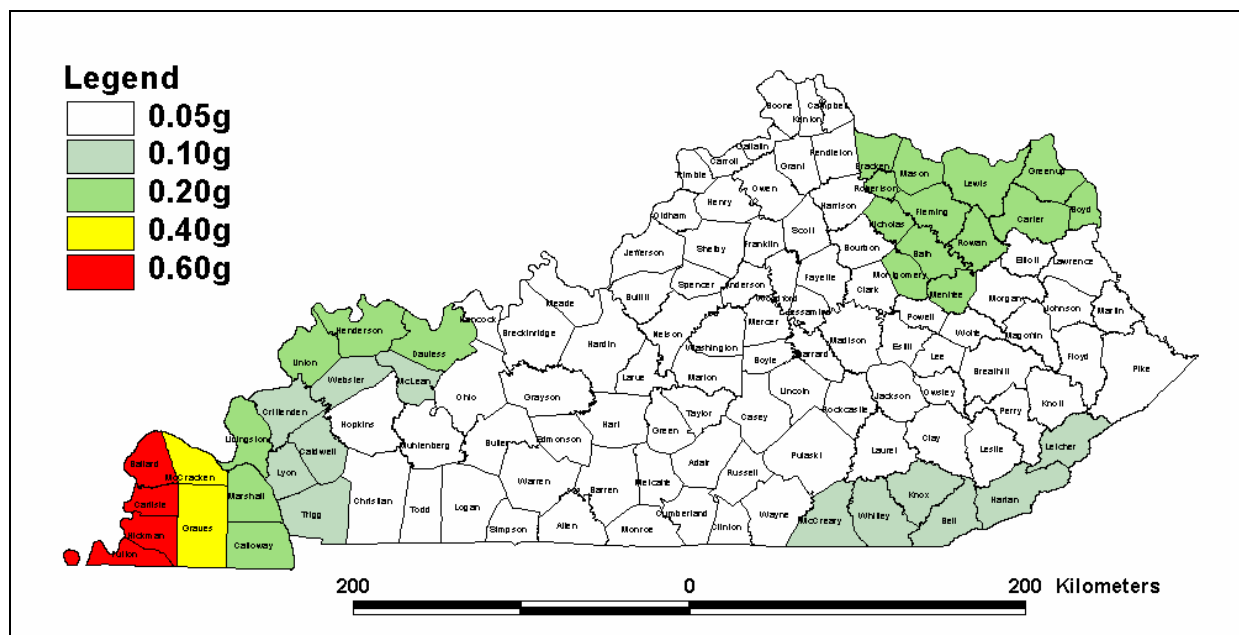


Figure 6. 0.2 second probable earthquake response acceleration (S_s) for Kentucky.

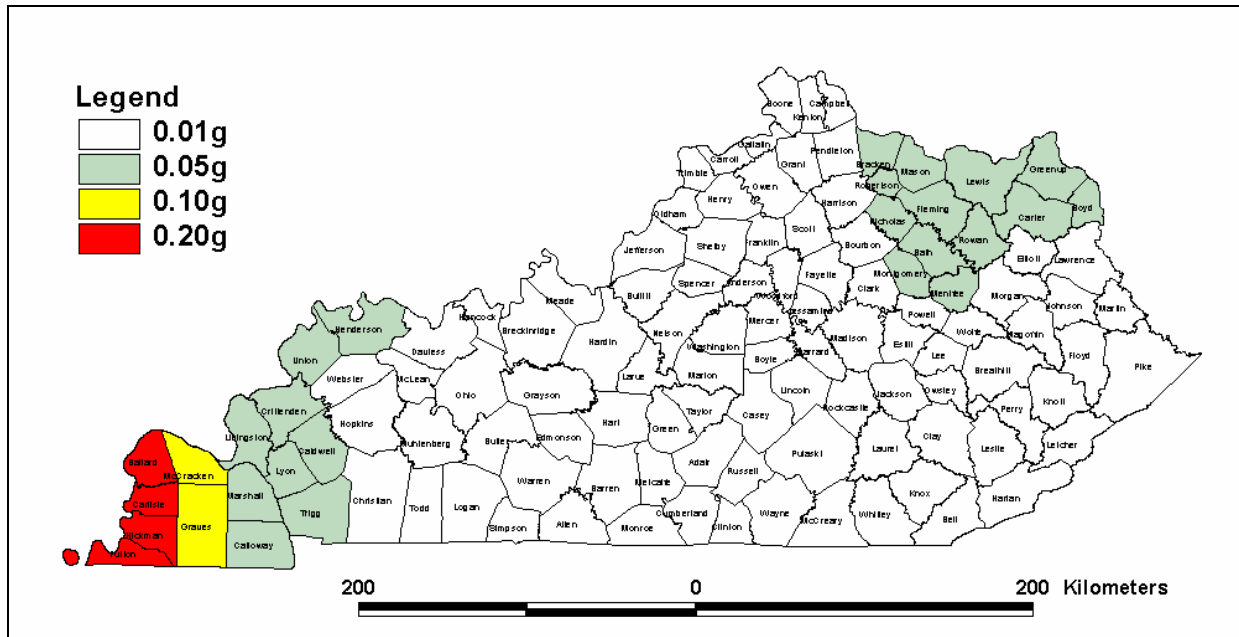


Figure 7. 1.0 second probable earthquake response acceleration (S_1) for Kentucky.

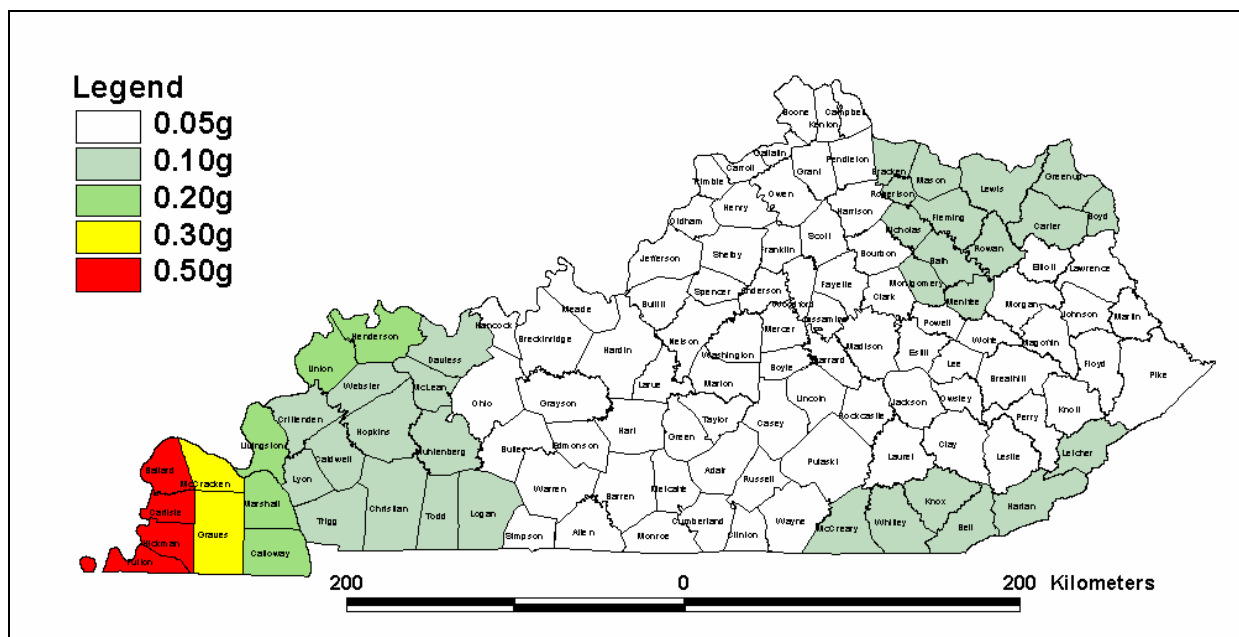


Figure 8. Maximum considered earthquake peak ground acceleration (PGA) for Kentucky. The maximum considered earthquake ground motion is equivalent to the ground motion with a 90 percent probability of not being exceeded in 500 years specified in KTC-96-4 (Street and others, 1996).

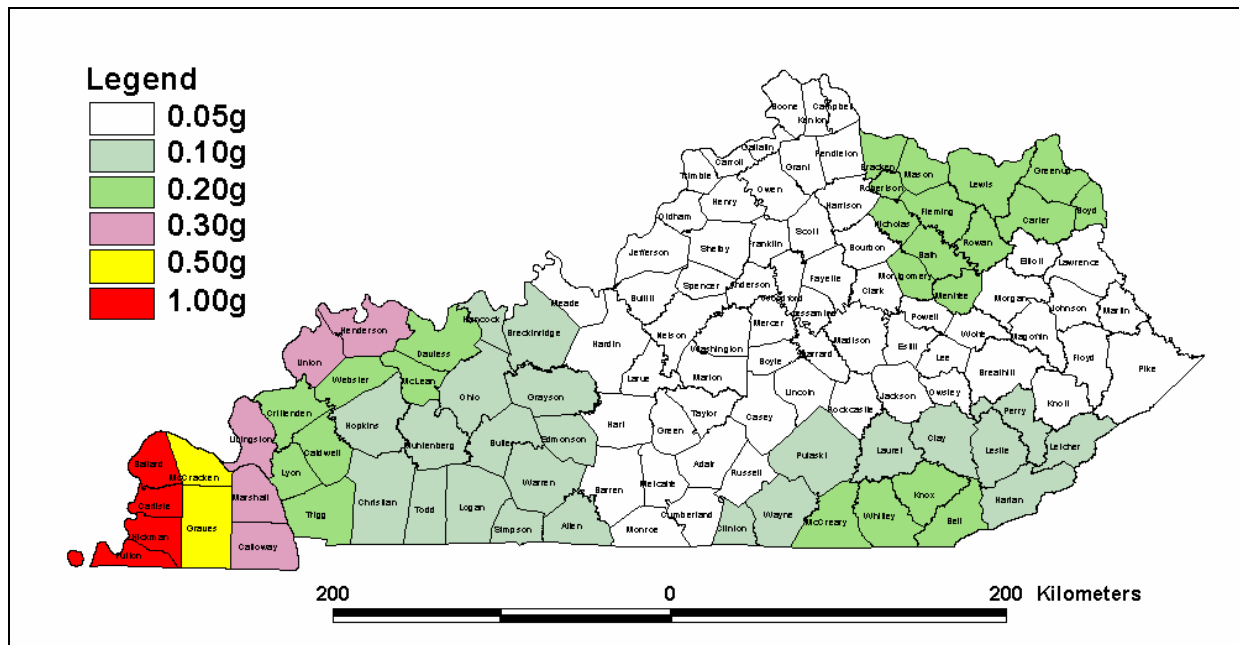


Figure 9. 0.2 second maximum considered earthquake response acceleration (S_s) for Kentucky.

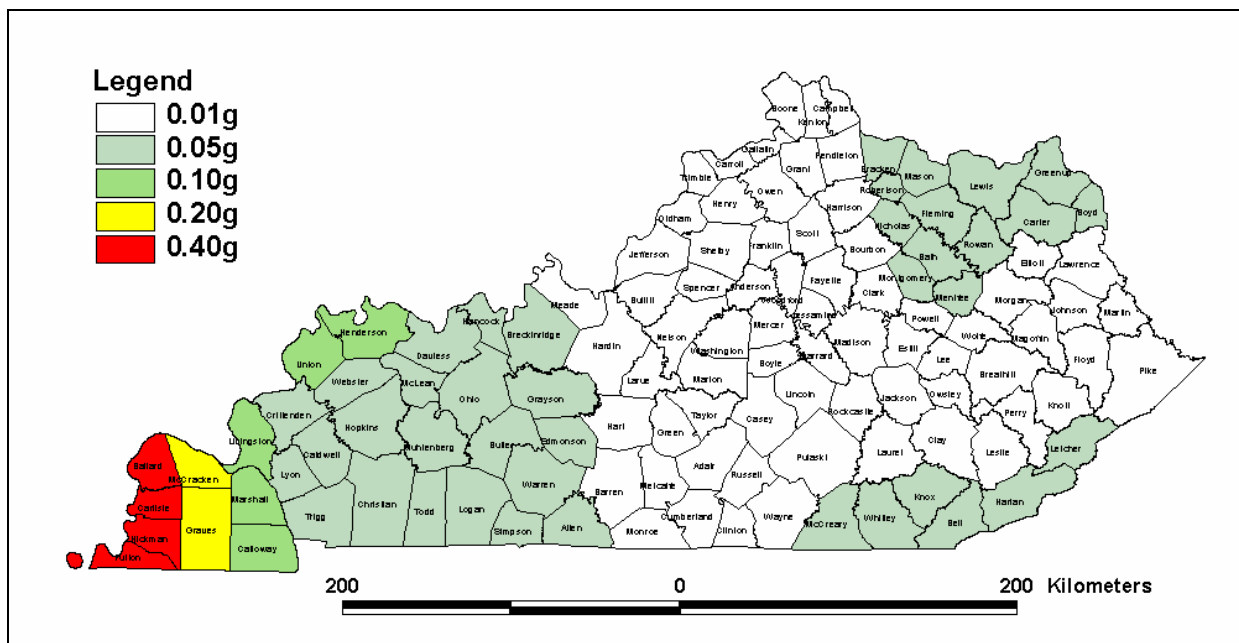


Figure 10. 1.0 second maximum considered earthquake response acceleration (S_1) for Kentucky.

Recommended Time History and Response Spectra

The recommended time histories were developed using the composite source model from the individual earthquake with the maximum ground motion and response spectra at each county seat in each earthquake scenario. The composite source model takes into account the source effects, including directivity and asperity, and three-dimensional wave propagation, and provides three-component ground motions that are physically consistent. The response spectra with 0.0, 2.0, and 5.0 percent damping ratios for the corresponding time histories were also developed. Detailed time histories and response spectra are included in Appendices A through C of *KTC-03-?* (Wang and others, 2003). Figures 11 through 13 show the recommended zones of time histories and response spectra for EE, PE, and MCE, respectively.

Selection of time histories and response spectra for use in design depends on (1) the earthquake and (2) the county being considered. For example, if MCE in McCracken County is considered, the time histories and response spectra of 0.30g-1MCE in Figure 13 should be used. Figures 14 through 17 show the acceleration time histories and response spectra for the zone of 0.30g-1MCE.

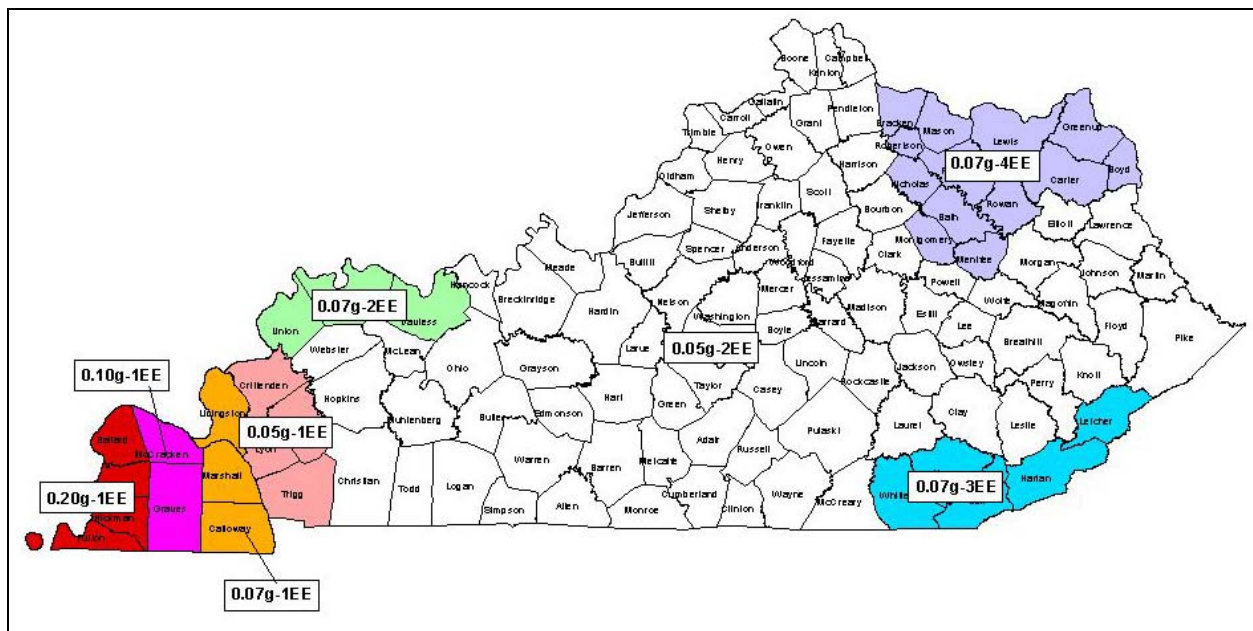


Figure 11. Recommended zones of the time histories and response spectra for the expected earthquake.

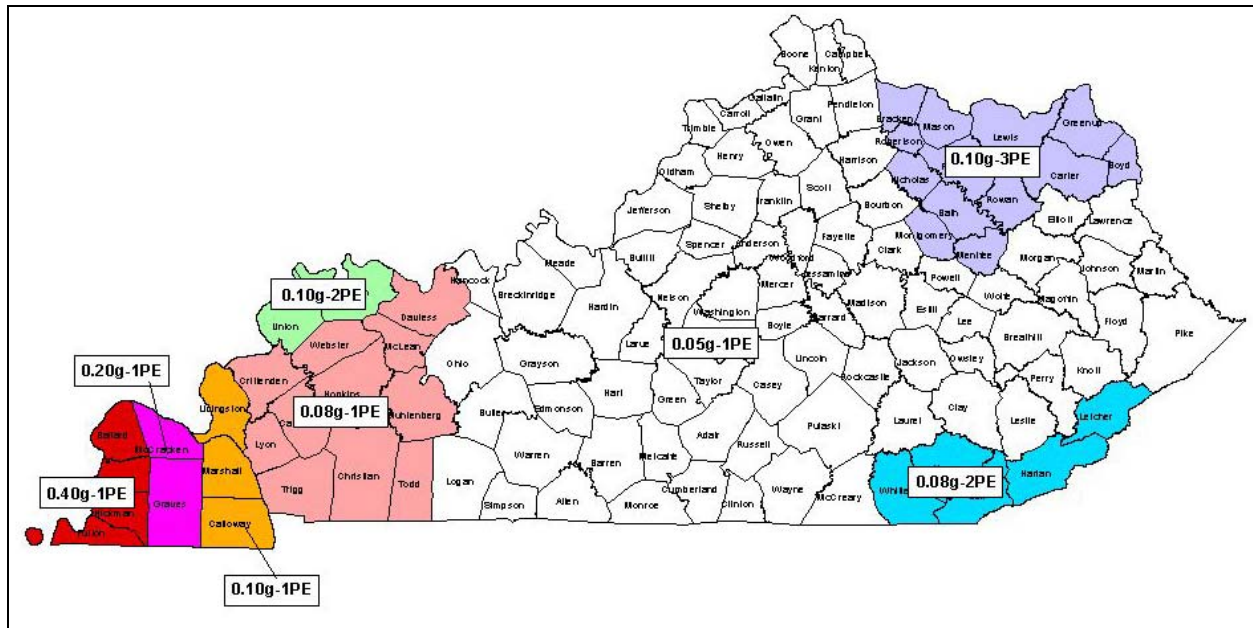


Figure 12. Recommended zones of the time histories and response spectra for the probable earthquake.

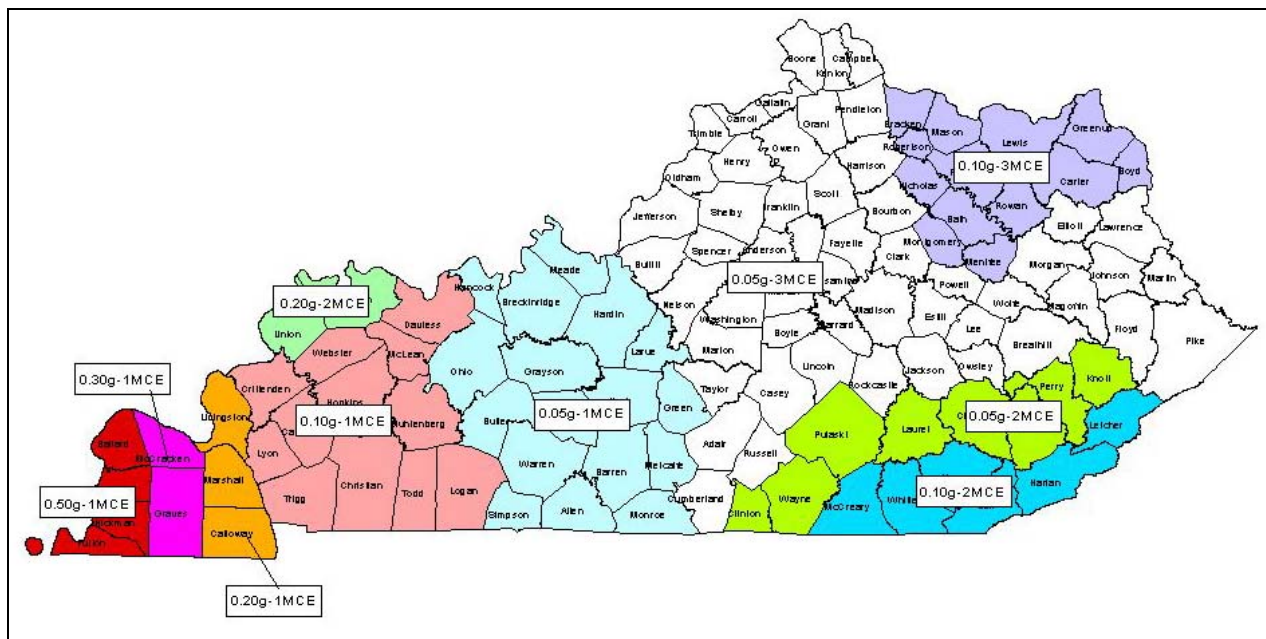


Figure 13. Recommended zones of the time histories and response spectra for the maximum considered earthquake.

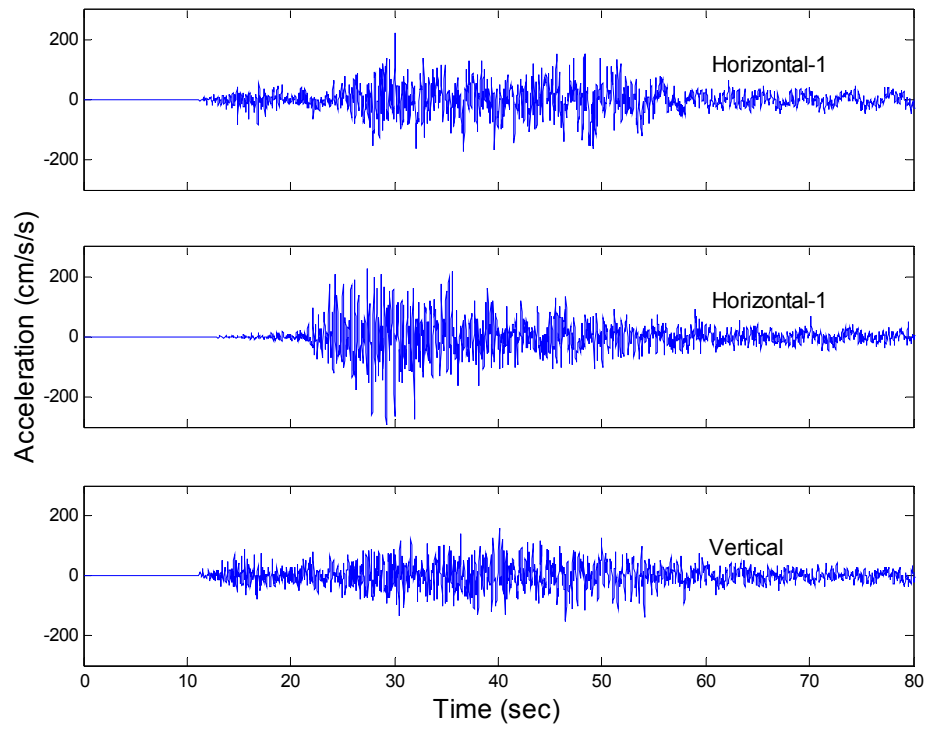


Figure 14. Acceleration time histories for the zone of 0.30g-1MCE.

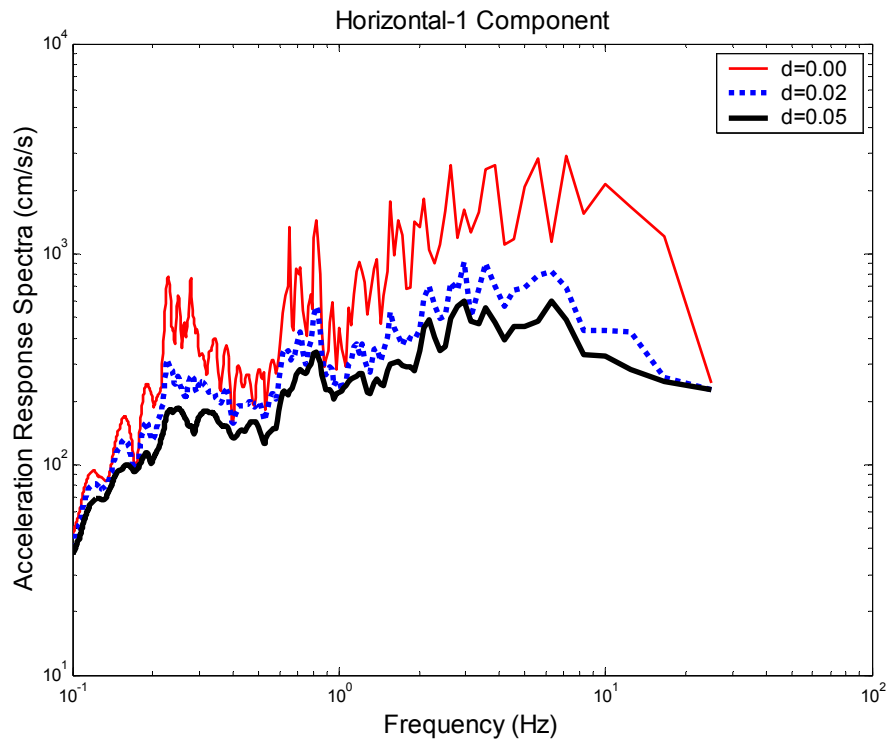


Figure 15. Pseudo-response acceleration (horizontal-1 component) for the zone of 0.30g-1MCE (damping ratio $d=0.00$, 0.02 , and 0.05).

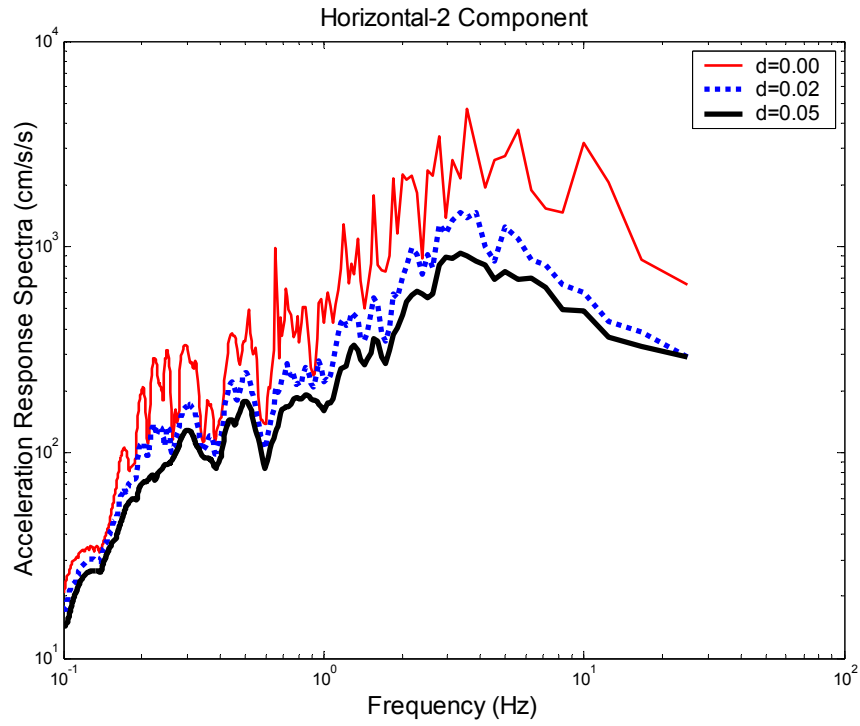


Figure 16. Pseudo-response acceleration (horizontal-2 component) for the zone of 0.30g-1MCE (damping ratio $d=0.00$, 0.02, and 0.05).

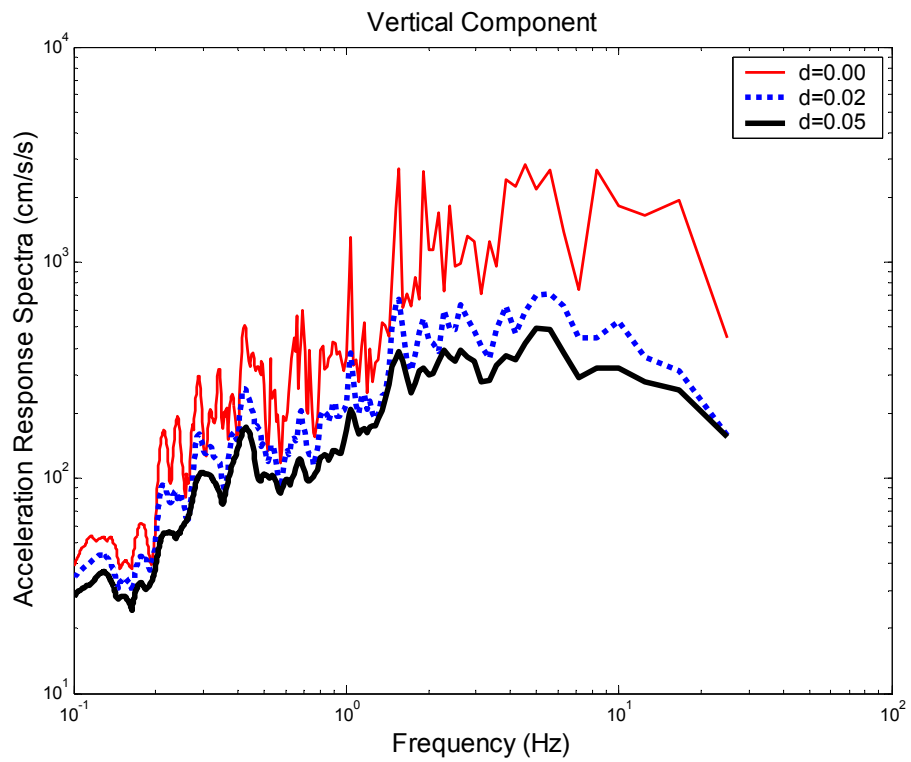


Figure 17. Pseudo-response acceleration (vertical component) for the zone of 0.30g-1MCE (damping ratio $d=0.00$, 0.02, and 0.05).